CLAIMS

I claim:

1. An end-terminal device bandwidth extension system comprising:

bandwidth extension circuitry for receiving a signal with frequency $\leq$ 4 KHz and providing an output signal including a signal with a narrowband component $\leq$ 4 KHz and an extended component > 4 KHz;

gain control for controlling the power of the extended signal and the narrowband signal; and

a loudspeaker coupled to the gain control for outputting the output signal.

2. The end-terminal device bandwidth extension system of claim 1, further comprising a microphone and a detector for determining ambient noise from the microphone and for providing a signal to the gain control in response to the detection.

3. The end-terminal device bandwidth extension system of claim 1, further comprising a first voice activity detector that detects the signal and mutes application of the bandwidth extension circuitry during pauses between speech signals in order to not extend spectrum of additive background noise.

4. The end-terminal device bandwidth extension system of claim 3, further comprising a second voice activity detector operating on the input signal and sampled faster than 8 KHz is used to compute an ambient noise power in the bandwidth extended spectral range.

5. The end-terminal device bandwidth extension system of claim 1, wherein ambient noise power is measured on the input signal to control the level of the extended signal.

6. The end-terminal device bandwidth extension system of claim 1, further comprising a user volume control to control information used in the output gain control.

7. The end-terminal device bandwidth extension system of claim 1, further comprising a user control over a level of the generated signal in the extended signal relative to the narrowband signal.

8. The end-terminal device bandwidth extension system of claim 1, wherein the input signal is up-sampled at a higher sampling frequency by using an interpolation mechanism.

9. The end-terminal device bandwidth extension system of claim 1, wherein the input signal is delay compensated before applying to the gain control.

10. The end-terminal device bandwidth extension system of claim 1, wherein the bandwidth extension circuitry includes an isolation filter for capturing a part of the spectrum in the 0-4 KHz range.

11. The end-terminal device bandwidth extension system of claim 10, further comprising an energy mapping function implemented as a non-linear function and applied to a signal output from the isolation filter.

12. The end-terminal device bandwidth extension system of claim 11, further comprising an output filter for capturing a part of a signal output from the energy mapping function in the extended frequency range.

13. The end-terminal device bandwidth extension system of claim 1, further comprising a loudspeaker compensation filter for approximately equalizing a loudspeaker frequency response.

14. The end-terminal device bandwidth extension system of claim 1, wherein the gain control combines the input signal and the extended signal so that the output energy is the same as the energy of the input signal.

15. The end-terminal device bandwidth extension system of claim 1, wherein the gain control combines the input signal and the extended signal so that the output energy is equal to a level set by a user of the end-terminal device.

16. The end-terminal device bandwidth extension system of claim 12, wherein the isolation filtering, the energy mapping, output filtering and loudspeaker compensation filtering are generalized to work in multiple frequency bands.

17. A network device, comprising:

an input interface;

a processor that generates a bandwidth extended signal derived from a far-end speech communication signal received at the input interface; and

an output interface to which the bandwidth extended signal is provided.

18. The network device of claim 17, further comprising a decoder to decode the far-end speech communication signal.

19. The network device of claim 17, further comprising an encoder to encode the bandwidth extended signal.

20. The network device of claim 18, further comprising an encoder to encode the bandwidth extended signal.

21. The network device of claim 17, wherein the processor is adapted to generate a derivative signal having at least one component at a frequency that is outside a bandwidth of the far-end speech communication signal, wherein such component is derived from the far-end speech communication signal, and wherein the processor comprises a combiner that combines the derivative signal with the far-end speech communication signal to generate the bandwidth extended signal.

22. The network device of claim 21, further comprising a gain controller to determine a gain for the derivative signal.

23. The network device of claim 21, further comprising a delay element to add delay to the far-end speech communication signal that is combined with the derivative signal to generate to the bandwidth extended signal.

24. The network device of claim 17, wherein the input interface is adapted to receive a narrowband far-end speech communication signal and the output interface is adapted to provide a wideband bandwidth extended signal.

25. The network device of claim 17, wherein the input interface is adapted to receive a narrowband far-end speech communication signal and the output interface is adapted to provide a bandwidth extended signal having a bandwidth that is at least as broad as a wideband signal.

26. The network device of claim 17, wherein the input interface is adapted to receive a 4 KHz signal far-end speech communication signal and the output interface is adapted to provide a bandwidth extended signal comprising frequency of > 4 KHz.

27. The network device of claim 22, further comprising a voice activity detector to detect whether the far-end speech communication signal contains speech at a given point in time, and wherein the gain for the derivative signal determined by the gain controller differs depending upon whether speech is detected by the voice activity detector.

28. The network device of claim 22, further comprising a voice activity detector to determine an interval in the far-end speech communication signal when speech is not present, and wherein the gain controller applies a different level of gain to the derivative signal during the interval as compared to a level of gain applied to the derivative signal prior to the interval.

29. The network device of claim 22, wherein the processor is adapted to determine the gain for the derivative signal by a method comprising the step of determining a level of ambient noise at a near-end of a far-end speech communication represented by the far-end speech communication signal.

30. The network device of claim 29, wherein the method further comprises the steps of:

receiving a near-end signal; and

determining the level of ambient noise at the near-end by reference to the near-end signal.

31. The network device of claim 30, wherein the level of ambient noise at the near-end is not determined by reference to the near-end signal at a given point in time when speech is detected in the near-end signal.

32. The network device of claim 30, wherein the level of ambient noise at the near-end is determined by reference to the near-end signal only during an interval when speech is not detected in the near-end signal.

33. The network device of claim 17, wherein the processor is adapted to generate a plurality of derivative signals each having at least one component at a frequency that is outside a bandwidth of the far-end speech communication signal, wherein such component is derived from the far-end speech communication signal, and wherein the processor comprises a combiner that combines the derivative signals with the far-end speech communication signal to generate the bandwidth extended signal.

34. A network device based method for bandwidth extension, the steps of the method comprising:

receiving a signal comprising a far-end speech communication;

generating a bandwidth extended signal derived from the received signal; and

providing the bandwidth extended signal to an output of the network device.

35. The method of claim 34, further comprising the step of decoding the received signal.

36. The method of claim 34, further comprising the step of encoding the bandwidth extended signal to provide an encoded bandwidth extended signal at the output of the network device.

37. The method of claim 35, further comprising the step of encoding the bandwidth extended signal to provide an encoded bandwidth extended signal at the output of the network device.

38. The method of claim 34, wherein the step of generating a bandwidth extended signal comprises the steps of:

filtering the received signal to generate a first signal having a frequency spectrum that is at least substantially confined to a first band-limited region;

generating a second signal by mapping at least one frequency component of the first signal to frequency spectrum that is outside the first band-limited region;

filtering the second signal to generate a third signal having a frequency spectrum that is at least substantially confined to a second band-limited region, wherein at least a portion of the second band-limited region includes frequency spectrum that is outside the first band-limited region; and

combining the third signal with the received signal to generate the bandwidth extended signal.

39. The method of claim 38, further comprising the step of sampling the received signal to generate a sampled version of the received signal, and wherein the step of filtering the received signal to generate a first signal comprises the step of filtering the sampled version of the received signal to generate the first signal.

40. The method of claim 38, further comprising the step of determining a gain for the third signal.

41. The method of claim 38, wherein the received signal that is combined with the third signal to generate the bandwidth extended signal is a delayed received signal, and further comprising the step of delaying the received signal to generate the delayed received signal.

42. The method of claim 34, wherein the received signal is a narrowband signal and the bandwidth extended signal is a wideband signal.

43. The method of claim 34, wherein the received signal is a narrowband signal and the bandwidth extended signal has a bandwidth that is at least as broad as a wideband signal.

44. The method of claim 34, wherein the received signal is a 4 KHz signal and the bandwidth extended signal is a signal comprising frequency of > 4 KHz.

45. The method of claim 40, further comprising the steps of:

detecting whether the speech communication contains speech at a given point in time; and

determining a different gain for the gain for the third signal depending upon whether speech is detected in the detecting step.

46. The method of claim 40, further comprising the steps of:

determining an interval in the speech communication when speech is not present; and

applying a different level of gain to the third signal during the interval as compared to a level of gain applied to the third signal prior to the interval.

47. The method of claim 40, further comprising the step of determining the gain for the third signal by a method comprising the step of determining a level of ambient noise at a near-end of the far-end speech communication.

48. The method of claim 47, further comprising the steps of:

receiving a near-end signal; and

determining the level of ambient noise at the near-end by reference to the near-end signal.

49. The method of claim 48, wherein the level of ambient noise at the near-end is not determined by reference to the near-end signal at a given point in time when speech is detected in the near-end signal.

50. The method of claim 48, wherein the level of ambient noise at the near-end is determined by reference to the near-end signal only during an interval when speech is not detected in the near-end signal.

51. The method of claim 34, wherein the step of generating a bandwidth extended signal comprises the steps of:

generating a plurality of derivative signals each having at least one component at a frequency that is outside a bandwidth of the received signal, wherein such at least one component is derived from the received signal; and

combining the derivative signals with the received signal to generate the bandwidth extended signal.

52. A network device based method, the steps comprising:

receiving an input signal;

generating an output signal, wherein the output signal represents a wider bandwidth version of a speech communication represented by the input signal; and

providing the output signal to an output of the network device.

53. The method of claim 52, further comprising the step of decoding the input signal.

54. The method of claim 52, further comprising the step of encoding the output signal.

55. The method of claim 53, further comprising the step of encoding the output signal.

56. The method of claim 52, wherein the step of generating an output signal comprises the steps of:

filtering the input signal to generate a first filtered signal having a frequency spectrum that is at least substantially confined to a first band-limited region;

generating a derivative signal having at least one component at a frequency that is outside the first band-limited region, wherein such at least one component of the derivative signal is derived from at least one characteristic of the first filtered signal;

filtering the derivative signal to generate a second filtered signal having a frequency spectrum that is at least substantially confined to a second band-limited region, wherein at least a portion of the second band-limited region includes frequency spectrum that is outside the first band-limited region; and

combining the second filtered signal with the input signal to generate the output signal.

57. The method of claim 52, wherein the step of generating an output signal comprises the steps of:

generating a derivative signal having at least one component at a frequency that is outside a bandwidth of the input signal, wherein such at least one component is derived from the input signal; and

combining the derivative signal with the input signal to generate the output signal.

58. The method of claim 56, further comprising the step of sampling the input signal to generate a sampled version of the input signal, and wherein the step of filtering the input signal to generate a first filtered signal comprises the step of filtering the sampled version of the input signal to generate the first filtered signal.

59. The method of claim 57, further comprising the step of determining the gain for the derivative signal.

60. The method of claim 57, wherein the input signal that is combined with the derivative signal to generate the output signal is a delayed input signal, and further comprising the step of delaying the input signal to generate the delayed input signal.

61. The method of claim 52, wherein the input signal is a narrowband signal and the output signal is a wideband signal.

62. The method of claim 52, wherein the input signal is a narrowband signal and the output signal has a bandwidth that is at least as broad as a wideband signal.

63. The method of claim 52, wherein the input signal is a 4 KHz signal and the output signal is a signal comprising frequency of > 4 KHz.

64. The method of claim 59, further comprising the steps of:

detecting whether the input signal contains speech at a given point in time; and

determining a different gain for the gain for the derivative signal depending upon whether speech is detected in the detecting step.

65. The method of claim 59, further comprising the steps of:

determining an interval in the input signal when speech is not present; and

applying a different level of gain to the derivative signal during the interval as compared to a level of gain applied to the derivative signal prior to the interval.

66. The method of claim 59, wherein the input signal represents a far-end speech communication, and further comprising the step of determining the gain for the derivative signal by a method comprising the step of determining a level of ambient noise at a near-end of the far-end speech communication.

67. The method of claim 66, further comprising the steps of:

receiving a near-end signal; and

determining the level of ambient noise at the near-end by reference to the near-end signal.

68. The method of claim 67, wherein the level of ambient noise at the near-end is not newly determined by reference to the near-end signal at a given point in time when speech is detected in the near-end signal.

69. The method of claim 67, wherein the level of ambient noise at the near-end is newly determined by reference to the near-end signal only during an interval when speech is not detected in the near-end signal.

70. The method of claim 52, wherein the step of generating an output signal comprises the steps of:

generating a plurality of derivative signals each having at least one component at a frequency that is outside a bandwidth of the input signal, wherein such at least one component is derived from the input signal; and

combining the derivative signals with the input signal to generate the output signal.

71. A network device based method, the steps comprising:

receiving an input signal at an input interface of the network device;

decoding the input signal;

determining an interval in the input signal when speech is not present in the input signal;

generating a derivative signal having at least one component at a frequency that is outside a bandwidth of the input signal, wherein such at least one component is derived from the decoded input signal;

determining a gain for the derivative signal to generate a gain-determined derivative signal, wherein a lower level of gain is determined for the derivative signal during the interval as compared to a level of gain applied to the derivative signal prior to the interval;

delaying the decoded input signal to generate a delayed input signal;

combining the gain-determined derivative signal with the delayed input signal to generate an output signal, wherein the output signal represents a wider bandwidth version of a speech communication represented by the input signal;

encoding the output signal; and

providing the encoded output signal to an output interface of the network device.